CALIFORNIA DIVISION OF MINES AND GEOLOGY

FAULT EVALUATION REPORT FER-243

SAN ANDREAS FAULT, SHELTER COVE AREA, HUMBOLDT COUNTY

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INTRODUCTION

The northernmost on-land segment of the San Andreas Fault reportedly ruptured in 1906 near Shelter Cove in southern Humboldt County (Figure 1). Based on the observations of F.E. Matthes (Lawson, 1908) and remapping by Brown and Wolfe (1972), this segment of the San Andreas Fault was zoned under the Alquist-Priolo Earthquake Fault Zoning Act on the SE¼ Point Delgada quadrangle (Figure 2; CDMG, 1974).

The base map used for this Earthquake Fault Zone (EFZ) map is an enlargement from the southeastern portion of the 1949 15-minute Point Delgada quadrangle, which does not show existing roads, has a 100-foot contour interval, and is generally of poor quality by today's standards. The U.S. Geological Survey later issued the larger-scale 7.5-minute Shelter Cove quadrangle which shows numerous roads resulting from extensive subdivision and planned development in the Shelter Cove area and has a 40-foot contour interval. Although the Shelter Cove quadrangle carries a 1969 date, it was not available until after the 1974 EFZ map was prepared. Brown (1995) replotted the location of the San Andreas Fault on the newer map (Figure 3). He also re-interpreted the position of the northern end of the fault's main trace and omitted the secondary traces shown on earlier mapping. Other workers have contrasting opinions regarding the location and extent of the fault.

For these reasons, the San Andreas Fault near Shelter Cove is re-evaluated here for revised zoning under the Alquist-Priolo Act. Another reason for re-evaluating the EFZ map is that the criteria for zoning in 1974 were less restrictive and the zones were wider than are currently used (Hart, 1994). Because the Shelter Cove area is extensively subdivided and is under continued development, it is important to identify and locate the active fault traces as accurately as possible on the more readable base map in order to facilitate sales disclosures and the safe location of new structures.

SUMMARY OF AVAILABLE DATA

Geologic and Tectonic Setting

The Shelter Cove area is a geologically complex area whose history is only gradually being unravelled. Areal mapping has been impeded by few access roads, dense vegetation, and steep terrain. Initial mapping (1:62,500 scale) of the coast area by Beutner and others (1980) documented that the Shelter Cove coastal area was underlain by tectonostratigraphic units of the Coastal Belt of the Franciscan Complex. McLaughlin and others (1982, 1994) have continued mapping in the Cape Mendocino region, have further recognized the diverse nature of these rock units, and have proposed models for their origin. They divide the Coastal Belt of the Franciscan Complex into three terranes -- the Yager, Coastal and King Range Terranes (Figure 4). The latter two underlie the Shelter Cove quadrangle. The Coastal Terrane (late Eocene to Late Cretaceous) consists of sandstone and argillite with lesser amounts of basalt, limestone and blue schist. It is separated from the King Range Terrane on the west by the southwest-dipping King Range thrust fault. The latter terrane is further divided into the Point Delgada and King Peak Subterranes. The Point Delgada Subterrane (late Cretaceous) is a melange composed of pillow basalt, calcareous mudstone, sandstone, shale and blue schist and is exposed only in the coastal area between Point Delgada and Telegraph Creek. To the east and in presumed fault contact is the King Peak Subterrane (late Miocene and early Tertiary? age) composed mainly of sandstone and argillite with minor amounts of limestone, chert and basalt. It is penetratively deformed and sheared and contains belts of melange.

These tectonostratigraphic units were deposited along a trench/slope margin and subsequently accreted to the North American Plate, along with scrapings of the oceanic Farallon Plate. McLaughlin and others (1994) believe that the King Range Terrane was 1) deposited as far as 435 km (272 mi) south of Cape Mendocino and speculate that it was 2) rifted from the California margin and attached to the Pacific Plate about 14 million years ago (Ma) and 3) translated northward behind the Mendocino Triple Junction along the San Andreas transform fault. Accretion of the King Range Terrane to the North American Plate was by obduction, the suture being the King Range thrust fault (Figure 4). Their models are more complicated than described here, but McLaughlin and others (1982, 1983, 1985, 1994) have cast doubt as to the location of the San Andreas Fault, speculating that it either lies to the west of Point Delgada, or along the eastern margin of the King Range Terrane (Figure 4). McLaughlin and others (1983) also question the 1906 ruptures at Shelter Cove as being fault-related and state that the ruptures are as easily explained by seismically triggered landsliding. Others place the active 1906 trace of the San Andreas Fault onshore at Shelter Cove; however, they disagree as to the northerly extension of the fault (see discussion below).

Related to the complexity of the structure of Shelter Cove is the Mendocino Triple Junction (MTJ), which McLaughlin and others (1994) place in the vicinity of Petrolia about 20-30 km (12-20 mi) north of Shelter Cove (Figure 4). The MTJ marks the junction of the Pacific, Farallon (Gorda) and North American plates and migrated northwestward to form the propagating northern tip of the lengthening San Andreas Fault, beginning about 16 Ma. Associated with the northward migration of the MTJ is the cessation of subduction and development of a "slab window" (e.g. Dickinson and Snyder, 1979). According to Merritts and Bull (1989), who studied the development of terraces and uplift rates in the Cape Mendocino region, the MTJ is associated with a rapid uplift pulse that shifts northward through time like a ship and its wake. The maximum uplift rate for the last 100 ka is about 4 mm/yr at Randall Creek (south of Petrolia) and 2.8 mm/yr at Smith Gulch (Figure 4). At Point Delgada, the uplift rate is about 1 mm/yr in the last 45 ka (McLaughlin and others, 1983) and 1.2 mm/yr in the last 330 ka (Merritts and Bull, 1989). According to Merritts and Bull, the slab window (i.e. uplift pulse) of the MTJ passed Point Delgada about 300 ka, which now has a lower rate of uplift then it did when the MTJ was farther south.

If this model is correct, the northward migration of the MTJ and associated slab window creates a broad area of rapid uplift. Presumably the northward shift from Cascadia subduction to the transform regime of the San Andreas creates a complex region of distributive and rapidly changing stress. Thus, the San Andreas Fault in the Shelter Cove area should not only be quite young, but also more poorly defined northward from Shelter Cove. This model may help explain why various investigators reach different conclusions regarding the existence and location of the San Andreas Fault in the Point Delgada area.

1974 and Earlier

The earliest mapping of the San Andreas Fault in the Shelter Cove area was by F.E. Matthes who observed the surface ruptures shortly after the April 18, 1906 earthquake (Lawson, 1908, p. 54-58). Although Matthes did not have an adequate base map, he did prepare detailed sketch maps (Lawson, Fig. 10 and 11; reproduced here as Figure 5) to document the location of rupture traces. He was careful to distinguish the fault ruptures from landslide ruptures, based on his experience mapping the 1906 San Andreas Fault ruptures in Sonoma and Mendocino Counties. He identified the ruptures based on "disturbance of sod over a narrow belt and....a generally raised surface of this belt" (mole track) and "tearing of the sod along numerous diagonal fractures" (Riedel shears). Matthes implied that the dominant slip was horizontal (presumably right-lateral) but did not estimate the amount of slip due to the lack of fences and other features that crossed the fault. He did indicate a component of vertical offset in places (to 4 feet). He also states that the main trace follows "characteristic fault topography", indicating the occurrence of previous recent fault rupture.

According to Matthes, the ruptures extended from the coast at Shelter Cove (Deadman Gulch) to "Telegraph hill" (Figure 5).

He was unable to trace the fault to the north due to extensive landslides. Matthes also mapped three subsidiary faults (C, D, and E on Figure 5), but he does not describe the sense or magnitudes of slip other than to comment that 1) fault C is less pronounced than the main trace and that horizontal displacement is small and 2) fault D has a marked depression but that a fence crossing it showed no sign of horizontal shifting (although he speculates that the fence may have been repaired since the earthquake). He also portrayed fault trace E with queries, suggesting a lower degree of confidence as to the designation or location of this feature.

Landslides also were activated by the 1906 earthquake in the Shelter Cove area, as well as in the Cooskie Ridge and King Range areas to the north (Eakle in Lawson, 1908, p. 58). Some of the 1906 fault and landslide scarps and other features are recognizable on the 1941 and, to a lesser degree, on the 1954 airphotos (see below under Air Photo Interpretation and Field Observations).

Brown and Wolfe (1972) relocated Matthes' fault traces on the 1949 Point Delgada 15-minute topographic map, verifying the main trace using data provided in Lawson (1908) and their own interpretations of recent fault-produced geomorphic features observed both in the field and on pre-development airphotos. The locations of the subsidiary traces apparently were based entirely on data provided in Lawson (1908), because the traces are shown as dashed lines by Brown and Wolfe and no evidence of fault produced topography is noted on their map. Brown and Wolfe also mapped extensive landslide deposits in Shelter Cove and show these deposits to be faulted based on the development of linear scarps and trenches along the main fault trace. They projected the main trace northward based on northeast-dipping faults exposed in Kaluna Cliff north of hill 1471 (identified as "Telegraph 1472" on the later 1969 map and probably the same as "Telegraph Hill" of Matthes). According to Brown and Wolfe, the exposed fault dips 60°NE and offsets contrasting bedrock and surficial deposits (see Figures 2 and 7).

The 1974 Earthquake Fault Zones (formerly Special Studies Zones) Map was based almost entirely on Brown and Wolfe's mapping and their interpretation of Matthes' mapping with only minor additions by CDMG to extend three fault traces (mostly into the ocean) (Figure 2). Additionally, subsidiary fault C was extended northward based on Matthes' original mapping.

Post-1974

Although Brown and Wolfe (1972) recognized the uncertainty concerning the relationship between the ruptures at Shelter Cove and the faulting at Point Arena in Mendocino County 120 km (75 mi) to the south (Figure 1), they concluded that the Shelter Cove ruptures probably were continuous with the San Andreas Fault. In addition to the Lawson (1908) data, they cite the offshore topography (Nason, 1968) and seismic reflection profiling (Curray and Nason, 1967) to support the probable continuity of the Shelter Cove ruptures with Point Arena. However, Nason (1968) and Curray and Nason (1967) recognize the possibility that the main trace of the San Andreas Fault may lie just west of Point Delgada but provide no compelling evidence to support this possibility.

In support of large-scale on-land displacement are the geodetic measurements made between 1853 and 1942 (Marshall and others, 1994) which indicate 10 m of maximum displacement northwest of Shelter Cove for the 1906 earthquake. Breen and others (1987) made repeated triangulation surveys (1980-1985) in the MTJ region and inferred that the San Andreas Fault is locked to a depth of 15 km (10 mi) but is slipping at a rate of ~ 7 cm/yr below that depth.

A small-scale, 5-station geodetic network at Shelter Cove was measured between 1930 to 1976 and established a maximum right-lateral strain rate of 1.01 ± 0.18 (10^{-6}) rad/yr in a N13.2°W ± 4.5° direction (Snay and Cline, 1980). The 3.5 km (2 mi) wide network, which straddles the mapped 1906 trace of the San Andreas Fault, suggests a strain of 4.3 mm/yr across the net. The results were presumably smaller than what might be obtained if the network could be extended across a wider zone.

Other workers have questioned whether the 1906 ruptures at Shelter Cove are the main San Andreas Fault and suggest that these ruptures were caused by a minor fault or were due to landsliding. McLaughlin and others (1979; 1983; 1985) concluded that the San Andreas Fault, as mapped by Matthes (in Lawson, 1908), fails to significantly offset mineralized deposits dated at 13.8 ± 0.4 Ma and, therefore, could not be a major active fault. However, the mineralized locality applies only to fault D of Matthes (Figure 2 and 5), is discontinuously exposed, and is not the main rupture trace. They further concluded that the physiographic features and surface breakage that were ascribed to surface faulting by Matthes are as easily explained by seismically activated rotational landsliding. They also question right-lateral slip based on the lack of documented horizontal displacements.

Beutner and others (1980), who mapped the geology of the King Range and Chemise Mountain area that surrounds the Shelter Cove study area to the north, east and southeast, found little evidence to support a through-going active strike-slip fault on land and concluded that the San Andreas Fault and North American-

Pacific plate boundary probably lies west of Point Delgada. They also speculate that most of the "youthful fault features" identified on land in the Shelter Cove area -- presumably those mapped by Matthes (Lawson, 1908) and Brown and Wolfe (1969) -- may be "related to movements within the ancient landslide covering most of Point Delgada" area. They do show a number of discontinuous faults and lineaments, some of which they speculate may have had minor recent movement, within the Shelter Cove area as well as to the east and north. These faults are not plotted on the maps herein due to the reconnaissance nature and scale (1:62,500) of their mapping. Faults mapped in the Shelter Cove area are shown by Beutner and others (1980) to lie within a large ancient landslide.

Additional work by McLaughlin and others (1994) summarizes the tectonostratigraphic development of the Mendocino Triple Junction. The work identifies the Point Delgada-Shelter Cove area as part of the King Range Terrane, which had a very complex development since mid-Cenozoic time when most of the rocks were deposited, translated northward along a transform fault, and accreted to the North American Plate. Although they acknowledge the existence of the San Andreas Fault in the Shelter Cove area, they conclude that the main plate boundary would have to lie either offshore to the west of Point Delgada or the east along the suture of the King Range and Coastal Terranes. Part of this suture is mapped as the King Range thrust zone (Figure 4), a southwest-dipping thrust created during Pleistocene time and resulting from north-northeast directed compression associated with a 1-4 mm/yr uplift rate for the King Range.

In contrast, Dumitru (1991), employing fission track ages of apatite, concluded that rocks of Point Delgada (i.e. west of the fault as defined by Matthes) were uplifted about 12 million years ago while the rocks immediately to the east of the San Andreas Fault were uplifted and unroofed in the last 1.2 Ma. He further concluded that the SAF must have had about 1 km of vertical displacement in the last 1.2 Ma in addition to major Quaternary strike-slip offset.

Other recent work in the Shelter Cove area by Schill and others (1995) employed geologic and geomorphic mapping as well as trenching across one of Matthes' fault-rupture features. They found several pieces of evidence leading them to conclude that the "currently active trace of the SAF trends onshore near Point Delgada and extends at least as far north as 40°10', a distance of 13 km." The evidence cited in their abstract includes 1) a NW-striking vertical shear zone exhibiting right-lateral drag cutting a Quaternary landslide exposed at Shelter Cove, 2) a NW-striking, west-dipping slip plane in their trench excavation, 3) 8 m of right-lateral offset of the Telegraph Creek channel, 4) a prominent line of springs crossing the head of Kaluna Canyon, 5) an east-facing scarp and shutter ridge north of Horse Mountain, and 6) two exposures of a "youthful vertical fault with horizontal slip indicators" crossing prominent saddles and notches on the eastern flank of the King Range."

Unpublished data provided by Carol Prentice (personal communication, 1/17/96) of the U.S. Geological Survey amplified on the trench observations of Schill and others (1995). Two short trenches were excavated off of Landes Road about 600 m (2000 ft) north of Shelter Cove, but the fault was exposed only in Trench 1 (Figure 7). Trench 1 is about 14 m (45 ft) long and 3 m (10 ft) deep. It shows the SAF to have a variable but steep west dip and to offset colluvial soils with a reverse sense of displacement. Although the southwest dip could be interpreted as a landslide slip plane, the apparent reverse sense of separation is far more likely to be due to reverse or strike-slip faulting. Prentice also has copies of photographs taken in the Shelter Cove area in 1906 by Matthes. One of these is a view looking south along the fault showing a fresh west-facing scarp and linear pond on the slope south of Matthes' locality A (Figure 5).

Jordan Muller (1996) identifies the SAF localities cited by Schill and others (1995) and expands on their observations. His fault trace, which is plotted on an airphoto mosaic as a dashed line, is shown approximately on Figure 7. Muller's locality descriptions are quoted in Table 1. His localities 1 to 7 are plotted on Figure 7 as M1 to M7. His localities 8 and 9 lie 0.5 km (0.3 mi) and 2.5 km (1.5 mi) north of the Shelter Cove quadrangle and are not plotted.

Table 1.

1) 8-m right-lateral offset of Telegraph Creek and its steep banks along a ~N15°W trend.
2) An obvious scarp climbs the southern face of Telegraph Hill trending ~N13°W.
3) A depression 2 to 10-m wide, trending ~N3°W on top of Telegraph Hill.
4) A line of springs crossing the head of Kaluna Canyon.
5) A N-S trending scarp on Horse Mountain with a 0.5-1.5 m vertical headwall.
6) About 4 km north of Telegraph Hill, there is a disrupted E-W trending ridgeline.
7) A lineation of disrupted E-W ridgelines that appears as a shutter ridge in low-altitude, low-sun angle black-and-white photography.
8) A distinctive notch, like those common in strike-slip fault topography, in which a thin, youthful fault is oriented N31°W, 86°NE with slickenlines trending S34°E, 25° and N34°W, 14°.
9) Approximately 2 km north of the notch, a thin, youthful strike-slip fault is oriented N9°W, 74°SW, with one set of lineations measuring S57°E, 7° and extending the entire 10 m height of a Kings Range Road roadcut.

The localities generally correspond to items 3 to 6 of Schill and others (1995), discussed above. The "youthful" faults at localities 8 and 9 of Muller (1996) apparently are the same as item 6 of Schill and others (1995), but neither paper discusses the basis for determining recency. Muller concludes that the SAF main trace is a steeply-dipping strike-slip fault that trends onshore from near Point Delgada "and continues at least 13 km in a N1°-37°W trend." He further concludes that the subvertical orientation and northward trend of the fault make it unlikely that the fault trace veers to the northwest into the ocean as indicated by Brown (1995).

SEISMICITY

Seismicity in the Shelter Cove area was poorly documented until about 1974 when the Humboldt Seismic Network was established. Since that time a large number of earthquakes have been recorded in the Humboldt Bay - Cape Mendocino region. The seismicity map (Figure 6) shows the distribution of these earthquakes relative to the principal tectonic features and plates. Most of the seismicity is concentrated in the Gorda and North American Plates in the vicinity of the Mendocino Triple Junction. Additional seismicity (not entirely shown) outlines the Mendocino Fracture Zone (e.g. Hill and others, 1990; Oppenheimer and others, 1993).

The northern San Andreas Fault is not currently associated with earthquakes, indicating that the Pacific - North American plate boundary is locked. According to Hill and others (1990), the northern San Andreas Fault has been nearly aseismic at least since the mid-1930's when reliable instrumental data became available. However, a northwest-trending zone of seismicity east of the Shelter Cove quadrangle suggest activity on the Garberville Fault (Figure 6).

AIRPHOTO INTERPRETATIONS AND FIELD OBSERVATIONS

Air photos of the National Archive (1941) and U.S. Department of Agriculture (1954) were interpreted stereoscopically to evaluate active traces of the San Andreas Fault and associated geomorphic features (see References for flight lines and frame numbers). These features are identified on Figure 7 along with other geomorphic features that may be suggestive of active faulting but most likely are related to landsliding and ridgetop spreading. Field observations were confined to the Shelter Cove area and were limited both by time (November 14-16, 1995) and adverse conditions (fog, intermittent rain).

Topographically, the Shelter Cove area is variously benched and rolling to moderately steep, although it is locally developed by a network of paved roads (Figure 7). Relief along the San Andreas Fault is 160 m (500 ft) south of Telegraph Creek. The fault traverses steep vegetated slopes with relief of 500 m (1600 ft) between Telegraph Creek and Kaluna Cliff. The fault's position north of Kaluna Cliff is uncertain, but its projection crosses steep, vegetated terrane with relief up to 900 m (3,000 ft). This latter area is of very difficult access. The entire coastal area is undergoing rapid uplift (in excess of 1 mm/yr; Merritts and Bull, 1989) and rapid coastal erosion. The effect is to produce oversteepened coastal mountains that are undergoing accelerated erosion and extensive landsliding and ridgetop spreading that is most apparent within 3-5 km (2-3 mi) of the cliff-fringed coast. As such, the fault is difficult to map which has led others to question the northern extension of the SAF and whether the 1906 ruptures were due to faulting or landsliding (see preceding sections).

Despite the obscuring effect of erosion and landsliding, there is very strong geomorphic evidence for an active fault between the coast at Shelter Cove and Telegraph Hill to the north. This segment of the fault is well defined by a narrow and almost continuous zone of linear scarps (facing both east and west), right-laterally deflected drainages, sidehill benches, linear troughs and drainages, and a shutter ridge (Figure 7). These well-developed features strongly suggest a very active right-lateral fault with repeated Holocene surface ruptures for their formation. Moreover, some of the features (especially scarps) observed on the 1941 National Archive airphotos are sufficiently pristine as to suggest historic rupture. Quite certainly, this is the rupture segment mapped by Matthes in 1906 (Lawson, 1908) and remapped by Brown and Wolfe (1972), Brown (1995), Schill and others (1995), and Muller (1996).

The total displacement of the fault is not definitely known, but the minimum right-lateral offset at Telegraph Creek appears to be about 180-250 m (600-800 ft)(as was suggested by Brown, 1995). The sidehill benches and linear troughs to the south suggest even greater displacement and the right deflection of the beheaded Humboldt Creek suggests at least 900 m (3,000 ft) of right offset.

To the north of Telegraph Creek, the location of the active fault is indicated by a back(east)-facing scarp across a spur 250 m (800 ft) north of Telegraph Creek (Locality 1, Figure 7), a linear drainage, and a linear trough just east of survey marker "Telegraph 1472" (locality 2). The linear troughs and swales just north of Kaluna Cliff may also suggest the approximate location of the fault, but the active trace is generally obscured by recent landslide scars to the north and south (localities 3 and 4).

There is no clear evidence of a through-going active fault to the north or north-northwest, although linear drainages, saddles and other features suggest the locations of possible faults or fracture zones. However, these features have inconsistent trends and form a relatively broad zone (Figure 7). In addition, the features appear to be disconnected and do not align with systematically offset drainages or ridges. Some of the larger features (linear drainages and associated saddles) probably follow zones of weakness in the Franciscan melange and, although permissive of active faulting, are likely to be largely erosional (e.g. localities 5 to 9). The shorter, fresher linear scarps and troughs that occur high-up on ridges (e.g. localities 10 to 16) are most likely due to ridgetop spreading. Similar ridgetop trenches, ponds and scarps also occur well away from the San Andreas Fault (e.g. localities 16 to 18) and are believed to be caused by lateral spreading and settlement of ridges triggered by earthquake shaking. Many of the ridgetop features are flanked by benched and hummocky landslide topography suggesting a continuum between ridgetop spreading and deepseated landsliding. Ridgetop features created by seismic shaking are well-documented for the 1989 Loma Prieta earthquake (Hart and others, 1990; Ponti and Wells, 1991) and have been ascribed for other areas (e.g. see McCalpin and Irvine, 1995).

In general, my mapping of the SAF between Shelter Cove and Telegraph "hill" is similar to that of Brown (1995) and incorporates the observations of Schill and others (1995) and Muller (1996). I cannot verify Brown's (1995) trace in the Kaluna Cliff landslide scar, where he projects the fault to the northwest into the ocean. I also cannot verify most of Muller's (1996) trace north of Telegraph hill except where it locally coincides with short, discontinuous features mapped just north of Kaluna Cliff and at my locality 6 (Figure 7). Although well-developed ridgetop features (troughs, scarps) at Horse Mountain (my locality 11) cross Muller's trace, I cannot specifically verify the "N-S trending scarp" and "disrupted ridge" at his localities 5 and 6, respectively. Neither can I verify recent, fault-produced geomorphic features along his "lineation of disrupted E-W ridgelines" at his locality 7. It appears that Muller's trace is rather generalized and is projected to connect discontinuous features. I can verify several right-laterally deflected drainages and ridges in the Honeydew quadrangle between his localities 8 and 9 (0.5 km and 2.5 km north of map Figure 7), but these do not align as a single trace and only partly coincide with Muller's trace.

If the San Andreas Fault continues to the north, as proposed by Schill and others (1995) and Muller (1996), it is either less active than at Shelter Cove or it may split into multiple strands. In addition, the great relief and abundant landslides and lateral spread features tend to obscure the identification of active faults. In any case, the SAF is not well-defined north of Kaluna Cliff.

An additional effort was made to locate the active San Andreas Fault on airphotos (U.S.D.A., 1954) beyond the Shelter Cove quadrangle as far north as the Mattole River (Honeydew, Shubrick Peak, Cooskie Ridge, and Petrolia quadrangles), but without success. No through-going active fault could be identified in this area. However, it was noted that ridgetop spreading features are fairly abundant and well-developed within 3-5 km (2-3 mi) of the coast. Such features also were observed farther inland on King Peak, Bear Trap Ridge and Wilder Ridge. Most of these ridgetop features are flanked by large-scale landslides. Because ridgetop features and associated large-scale landsliding were noted in close proximity to the San Andreas Fault in the Shelter Cove quadrangle, it was hoped that a zone of well-developed ridgetop features to the north might suggest the approximate position of the fault to the north. Instead, the well-developed ridgetop features noted near the coast to the northwest are most likely related to gravity failures associated with the rapidly uplifting and oversteepened coastline. The other ridgetop features farther inland are scattered and not as well developed, but may suggest the general location of the SAF or some other active fault. However, this suggestion is highly speculative.

The subsidiary faults of Matthes also were evaluated (Figure 5). Fault C of Matthes is probably the same as the linear trough with two closed depressions mapped by this writer at locality 19 (Figure 7). This feature is very fresh-looking on the 1941 photos and no doubt ruptured in 1906. To the southeast a very fresh, west-facing scarp and three interconnecting southeast-facing scarplets -- all without vegetation on the 1941 photos -- also may be 1906 ruptures. However, whether they are caused by faulting or landsliding (landslide deposits and shears are prominently displayed in the cliffs below) is difficult to determine. Both the linear trench and main scarp extend into large erosional gullies that drain into Shelter Cove. At the base of the cliff, a terrace deposit reported to be about 44,800 years old (McLaughlin and others, 1983) is significantly deformed. Approximately at locality 20, a north-trending shear zone offsets the marine-nonmarine terrace contact about 1.5 or 2 m (5 or 6 ft) down to the east. This may coincide with the gully projection of the linear trough that reportedly ruptured in 1906. A few hundred feet to the east, the terrace sequence is folded into a syncline near the gully projection of the west-facing scarp. Farther to the east, the young terrace deposits are abruptly downwarped and possibly faulted against sheared and landslid Franciscan sandstone and mudstone along the projection of the main trace. According to Carol Prentice (personal communication, 1996), the main trace is exposed in the cliffs but can only be seen after winter storms have removed most of the sand from the base of the cliff. Because deformation of the terrace deposits suggests late Quaternary tectonic deformation (vs. landsliding), it is possible that the trench and scarps in the bench above 120 m (400 ft) elevation also are tectonic. The crude left-stepping pattern formed by the main trace and these two western subsidiary traces may also suggest a tectonic origin. However, gravity adjustments associated with the steep cliff at Shelter Cove no doubt played a role in the development of these features.

Subsidiary fault D of Matthes (Figure 5) also may be identified on the 1941 and 1954 air photos at locality 21 (Figure 7). Here a very fresh, 150 m (500 ft) long linear, northeast-facing scarp can be seen on the low ridge between Telegraph and Humboldt Creeks. This feature cannot be followed continuously to the southeast (as mapped by Matthes) due to the presence of landslides, some of which have very fresh-scarps that also may have been active in 1906 along the south flank of Telegraph Creek. Other youthful landslide features also occur to the southeast on both sides of Humboldt Creek, which shows a large right-lateral deflection. According to Matthes, fault D could be traced "to the south over the grassy hills [where] it is found to disappear somewhere near the head of a little gulch shown on the map." The gulch referred to may be at locality 22, which is a linear gulch flanked by a sharp east-facing scarp. This scarp appears to be truncated to the south by a east-west trending landslide scarp. However, other northwest-trending features (subtle scarp, trough) can be seen on the airphotos farther to the southeast. The airphotos suggest no surface connection between localities 21 and 22, except for short east-facing scarp in a landslide(?). Although it is possible that Matthes may have partly mistaken landslide ruptures for faults, he made a major point of being able to distinguish between strike-slip fault and landslide features. I was unable to verify the suggestion of McLaughlin and others (1985) that this trace of the fault has been "largely inactive" in the last 13.8 ± 4 Ma.

Subsidiary fault E of Matthes could not be verified by geomorphic features on the airphotos or on the ground. However, a linear, northeast-trending trough was identified at locality 23 about 200m (650 ft) west of the assumed location of his trace E (Figures 2, 5 and 7). This 300m (1000 ft) long trough, which has a closed depression near its northeast end, is similar in orientation to other northeast-trending scarps and troughs higher on the ridge to the southeast. All of these features are believed to be due to landsliding and lateral spreading of the ridge toward the northwest. A detailed map prepared by Northern

Geotechnical Incorporated (1987) for a site development shows the stepover area of this trough where it crosses Shelter Cove Road and recommended a 50-foot construction setback. A roadcut log across part of this feature shows a set of northwest-trending, steeply-east dipping faults in highly fractured Franciscan bedrock but does not show them to offset the overlying soil/colluvial units. The roadcut features and soil units were not well-exposed at the time of my visit.

CONCLUSIONS AND DISCUSSION

The preponderance of evidence strongly supports the existence of an active right-lateral fault that extends for at least 3 km (2 mi) from Shelter Cove to Kaluna Cliff (Figure 7). The almost continuous line of linear troughs, scarps, right-laterally deflected drainages and other features south of Telegraph "hill" are particularly well-defined and pristine, indicating repeated Holocene rupture as well as rupture in 1906. Although the fault passes through a large, recently active landslide complex, which also was partly active in 1906, fault displacement apparently was large enough to leave a well-defined fault signature in the upland surface, as reported by Matthes in 1906 (Lawson, 1908)(moletracks, left-stepping fissures, linear scarps and troughs, closed depressions).

To the north of Kaluna Cliff, the Holocene-active trace of the fault is difficult to follow, being obscured by active landsliding, erosion, and heavy vegetation. The active main trace also is partly obscured in the landslide cliffs above Shelter Cove, although Schill and others (1995) apparently observed the fault in landslide deposits exposed in the cliff. To the south, the fault generally aligns with traces of the San Andreas Fault mapped on the ocean floor by Curray and Nason (1967), Nason (1968), and McCulloch (1989).

Auxiliary traces of the San Andreas Fault mapped by Matthes (Figure 5) could only be verified in part. His trace C, as remapped from airphotos, appears to be comprised of a linear trough and a scarp interconnected by a set of left-stepping scarps that are closely associated with the main trace. Although these features may partly or largely owe their development to landsliding, they generally align with the main San Andreas Fault (Figure 7). In addition, the features are very fresh-looking on the 1941 airphotos and almost certainly developed in the 1906 earthquake. Fault D of Matthes apparently is verified at localities 21 and 22 where it aligns with linear, northwest-trending scarps and the right-laterally deflected drainages of Telegraph and Humboldt Creeks (Figure 7). The scarps are very fresh-looking on the 1941 photos, which is consistent in location and orientation with the 1906 ruptures reported by Matthes.

However, fault D is poorly defined between localities 21 and 22. Although the features used to define fault D may be partly due to landsliding, they seem to coincide with and verify the fault D ruptures reported by Matthes. Fault E of Matthes could not be verified as a recent geomorphic feature. Possibly it is the linear trough and sidehill bench I mapped about 200 m (650 ft) to the west as a landslide/lateral spread feature (Figure 7).

The main trace of the San Andreas Fault could not be mapped to the north or northwest of Kaluna Cliff with any degree of confidence. I could not verify the inferred northwest projection of Brown (1995; see Figure 3), which was based on an assumed 45°SW-dip and lack of outcrop along the coast to the north. This seems to be in conflict with Brown's previous observations of 60°NE-dipping faults in weathered rocks and colluvium at Kaluna Cliff (Brown and Wolfe, 1972), although those faults may be older shears in bedrock and surficial materials reactivated by landsliding. In any event, it seems more reasonable to assume that the fault is steep to vertical (like most strike-slip faults) and continues in a general N10°W direction (Figure 7). However, a more northerly alternative also could not be mapped and no compelling evidence was observed on air photos in the Shelter Cove quadrangle or adjacent Honeydew quadrangle to suggest the existence of a through-going active trace of the San Andreas. Moreover, some of the fault features reported by Schill and others (1995) and Muller (1996) between Kaluna Cliff and latitude 40°10' north could not be verified as indicative of an active right-lateral fault. To be sure, there is an abundance of north-trending drainages and associated features that are locally permissive of active faulting. But these features do not align and are most likely explained by a combination of erosion and landslide/lateral spread processes (Figure 7).

The lack of a well-defined surface trace of the San Andreas Fault does not necessarily mean no fault exists to the north. The model of a northward migrating Mendocino Triple Junction (MTJ) and lengthening San Andreas Fault seems to demand that the fault continue to the north in some manner. However, the model implies that the fault decreases in age northward and may be quite young in the Shelter Cove area. If the MTJ is only 20-30 km (12-20 mi) to the north or northwest and is somewhat broad and ill-defined (Figures 4 and 6), then the San Andreas Fault may be ill-defined and composed of multiple strands as it approaches the MTJ. Thus, it may be most reasonable to expect the fault at Shelter Cove to project northward as a progressively ill-defined feature with multiple, discontinuous surface traces. With the high rate of erosion and landsliding/lateral spreading operative north of Shelter Cove, I feel very uncertain identifying the inferred traces of the fault north of Kaluna Cliff as active faults. This limitation is highlighted by the belief that extensive ridgetop spreading and landsliding probably occurred during the 1906 and other recent earthquakes based on reconnaissance air photo interpretations made as far to the north and northwest as the Mattole River.

In summary, the evidence supports an active trace of the San Andreas Fault through Shelter Cove. The mapped trace need not be the only trace and other traces to the west and east have been proposed (e.g. Nason, 1968; McLaughlin and others, 1994; Griscom and Jachens, 1989). Very likely, the definition and age of the fault diminishes northward reducing the expectation or need for a continuous, well-defined surface trace.

RECOMMENDATIONS

Based on information presented here, it is recommended that the Earthquake Fault Zone shown on the SE¼ Point Delgada quadrangle be revised to reflect the revised locations of the main and auxiliary traces (includes traces C and D of Matthes) of the San Andreas Fault as shown on Figure 8. These faults meet the zoning criteria of sufficiently active (i.e. Holocene) and well-defined as described in Hart (1994). The fault traces shown on Figure 8 are based on this FER (Hart, 1996) with the exception of the main trace north of "Telegraph 1472", which is from Muller (1996).

Since the fault is not well-defined north of Kaluna Cliff, the zone should be terminated a short distance to the north. A note should be placed on the EFZ map to reflect the uncertainty of the fault's position to the north and/or the fact that the fault is obscured by landslides in that area.

The auxiliary fault trace E of Matthes could not be verified as a fault (although it may in part have been a landslide feature activated in 1906) and should be withdrawn from zoning. It is further noted that Matthes showed this fault trace as queried, distinguishing it from his other mapped traces.

The revised EFZ map should cite this FER (Hart, 1996) and Muller (1996) as references. Lawson (1908) and Brown (1995) also should be cited as they confirm the location of active fault traces.

Report reviewed and approved. William A. Bryant CEG #1554 2/10/97

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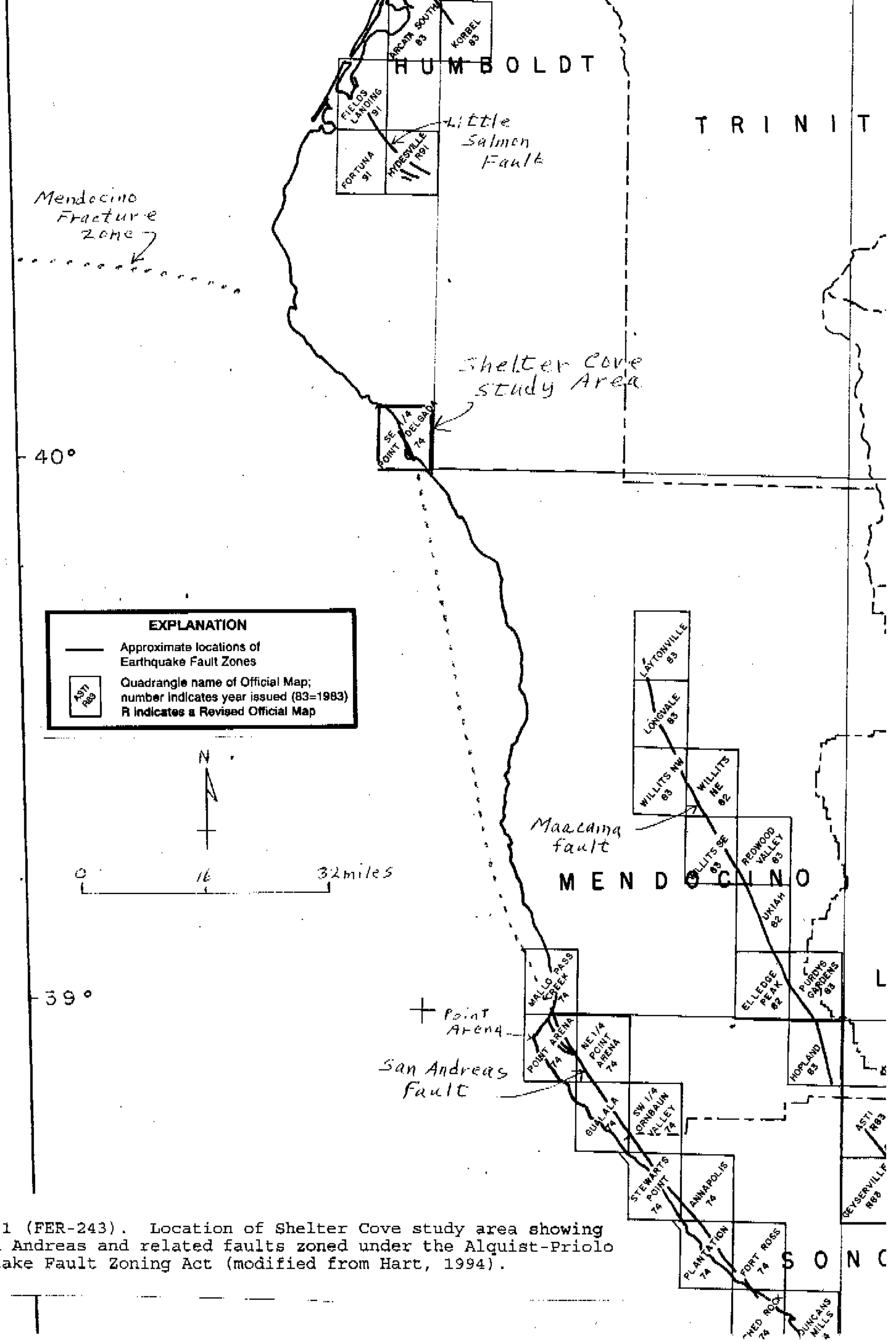


Figure 1 (FER-243). Location of Shelter Cove study area showing the San Andreas and related faults zoned under the Alquist-Priolo Earthquake Fault Zoning Act (modified from Hart, 1994).

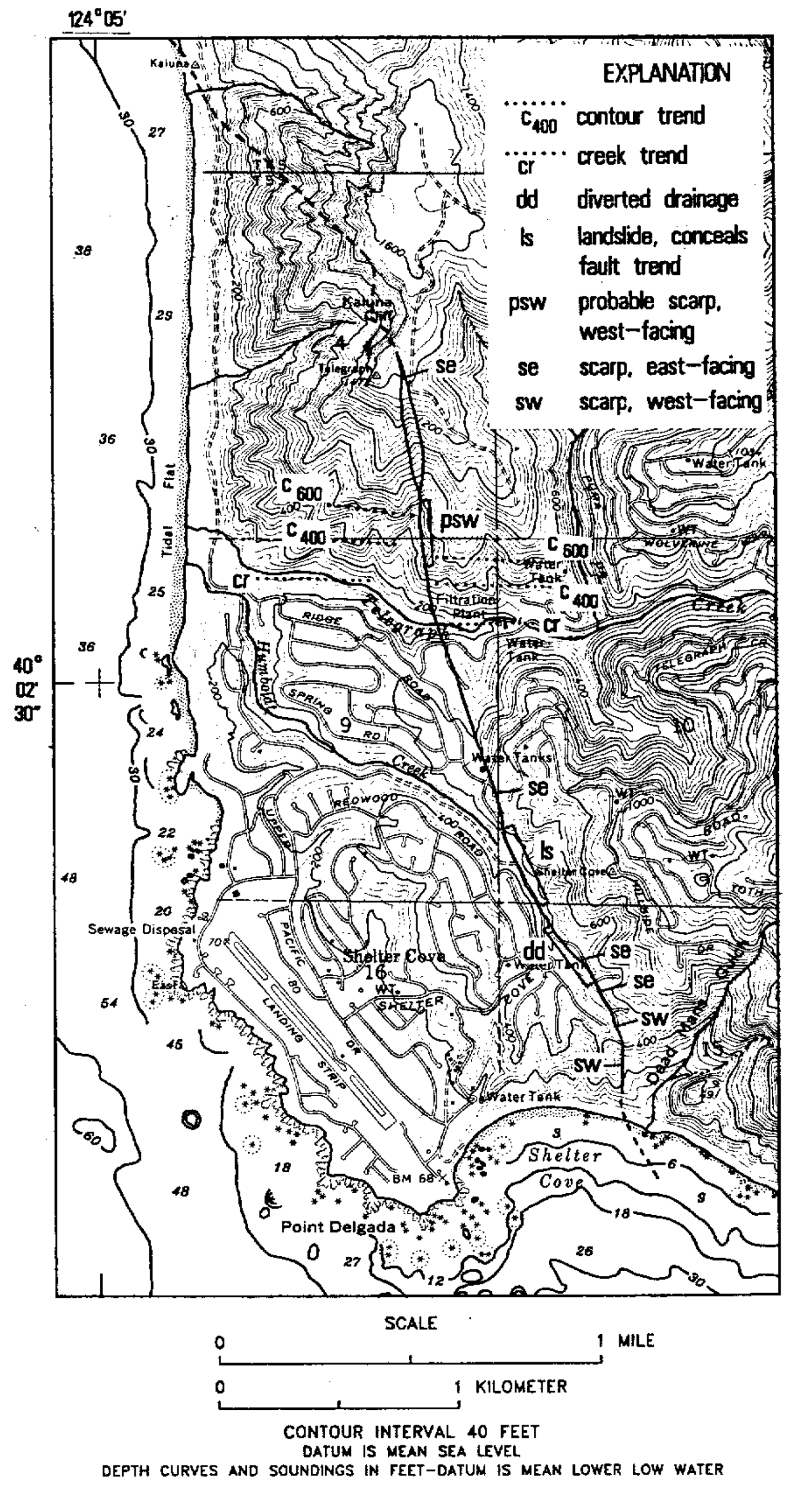


Figure 3 (FER-243). Location and geomorphic evidence of main trace of San Andreas fault at Shelter Cove (from R.D. Brown, 1994, Fig. 4).

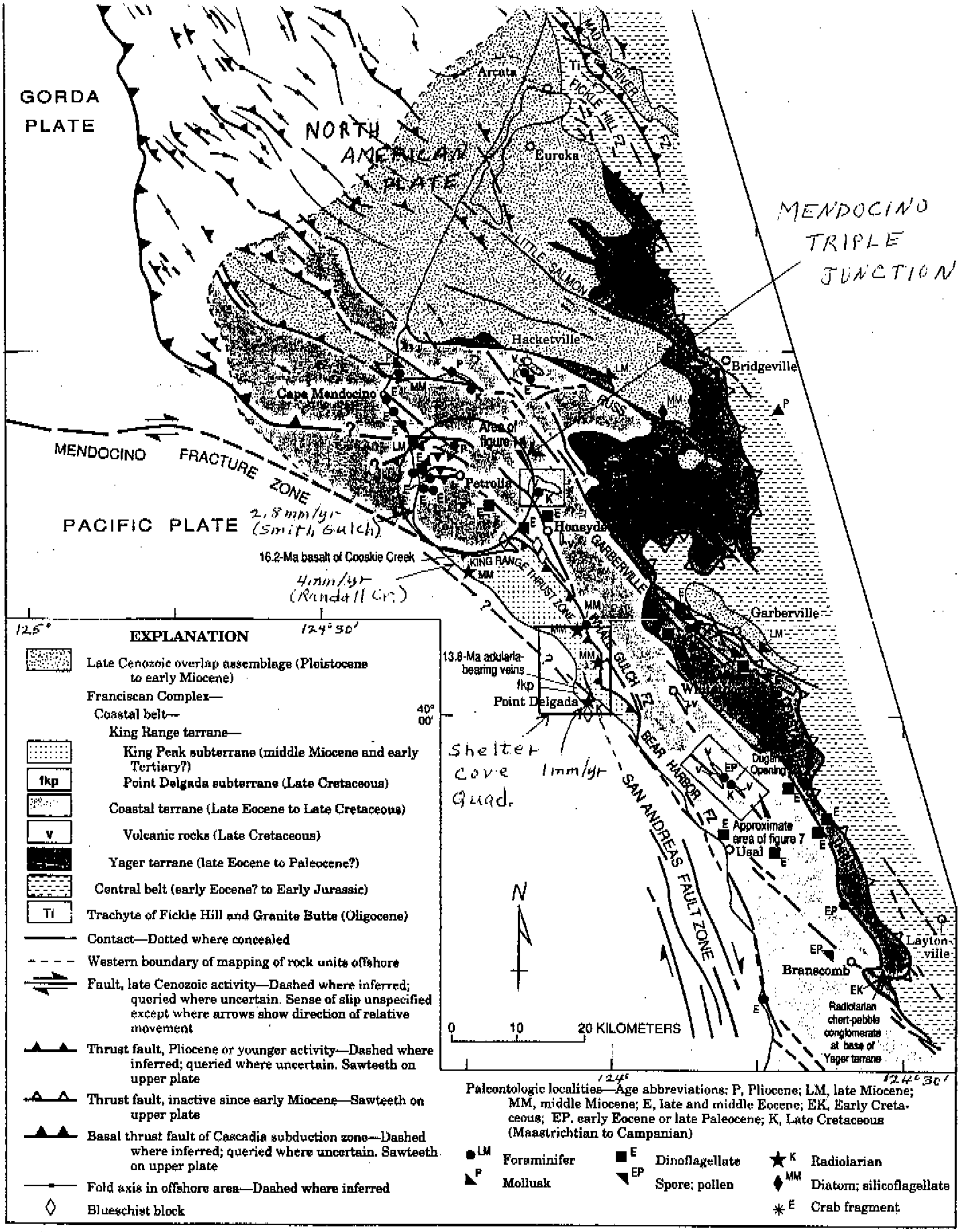
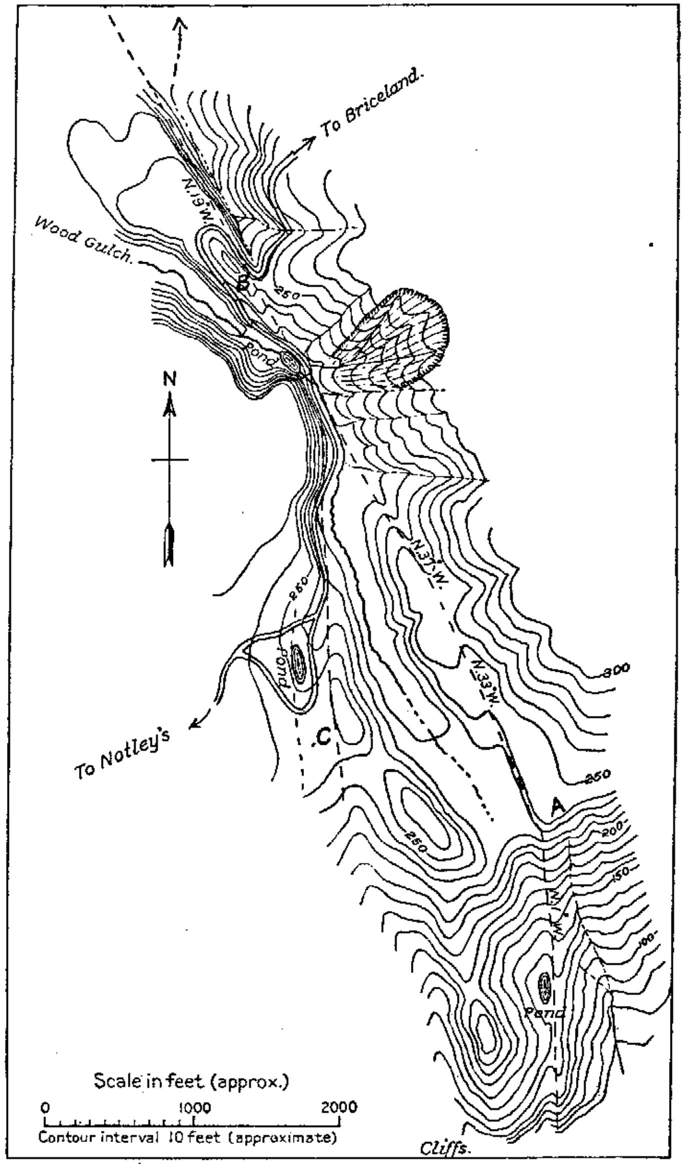
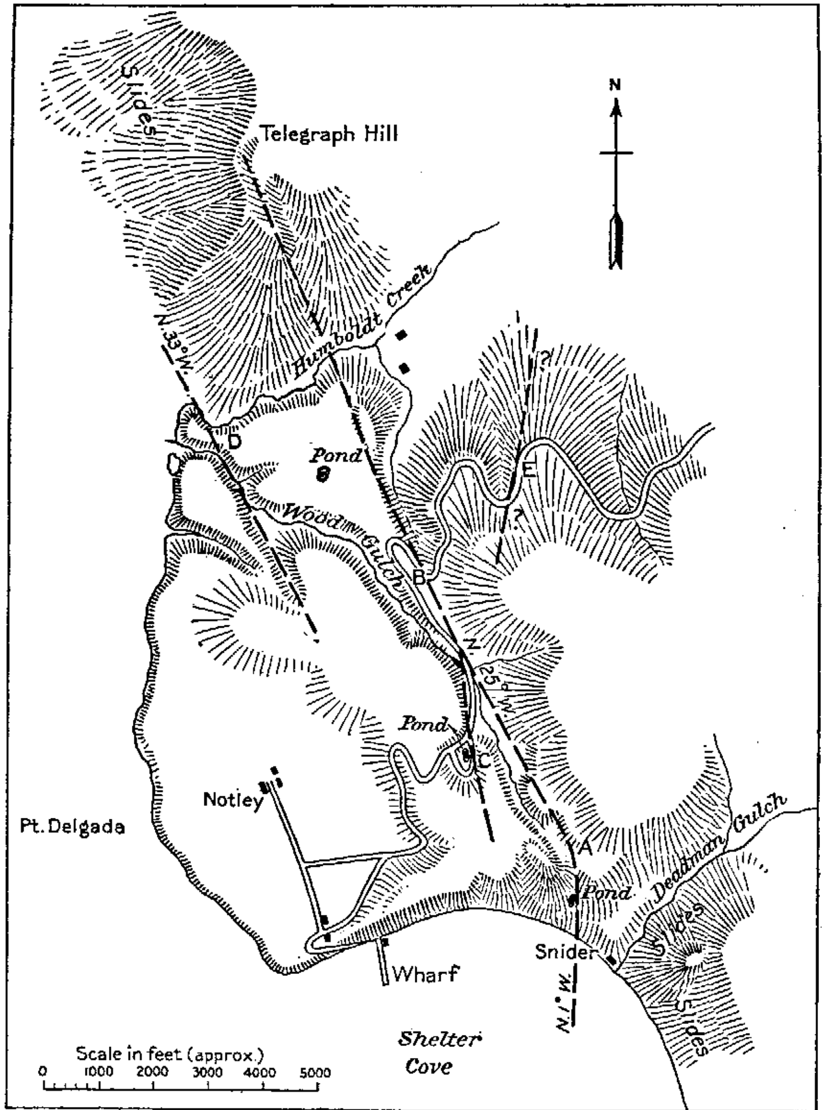


Figure 4 (FER-243). Geologic map of the Cape Mendocino region showing major tectonostratigraphic terranes and structures (from McLaughlin and others, 1994, Fig. 2), with selected uplift rates from Merritts and Bull (1989).

Figure 5 (FER-243). Sketch maps of 1906 San Andreas fault rupture at Shelter Cove by F.E. Matthes (from Lawson, 1908, Figs. 10 and 11).



(Fig. 10.)—Map of country traversed by fault to north of Shelter Cove, Humboldt County.



(Fig. 11.)—Map of country north of Shelter Cove, Humboldt County, showing auxiliary faults in relation to main fault.

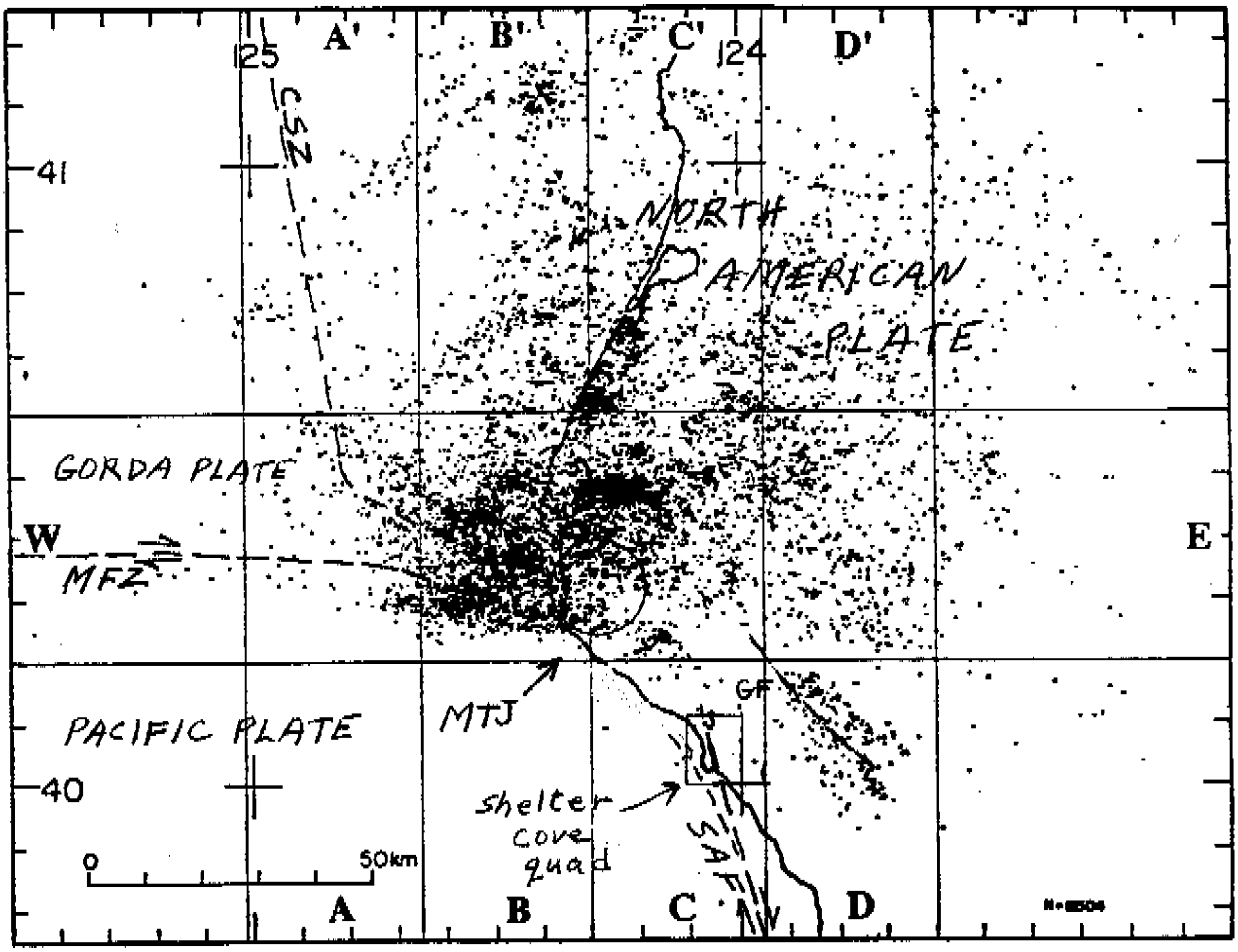


Figure 6 (FER-243). Map showing seismicity of the Mendocino Triple Junction (MTJ) region (from McPherson, 1992). Location of MTJ based on McLaughlin and others (1994). San Andreas Fault (SAF), Mendocino Fracture Zone (MFZ), and seaward edge of the Cascadia Subduction Zone (CSZ) separate the principle tectonic plates. GF is the Garberville fault.

Figure 8 (FER-243). Map of Holocene-active fault traces in the Shelter Cove 7.5-minute quadrangle recommended for revised zoning of the SE¼ Point Delgada Earthquake Fault Zones Map. Locations of fault traces are based on Hart (this FER), except for the main trace north of "Telegraph 1472", which is based on Muller (1996).